Competition in the Market for NASDAQ-listed Securities

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October 16, 2005

ABSTRACT

Intense competition among the six market centers that trade NASDAQ-listed securities has, under decimals, led to development of significant differences in their quoting behavior, execution costs, and information shares. Non-NASDAQ markets contribute sufficiently to the best bid and offer that using only NASDAQ quotes overstates spreads by four cents. ECNs are more different than alike due to differences in depths of their limit order books and trading clienteles. Liquidity seems to be the foremost concern of informed traders, as price discovery for less active stocks occurs on the venues that provide liquidity, whereas for more active stocks informed trades are executed on venues that provide both anonymity and liquidity. We find that market fragmentation causes 14% of NBBOs to be locked or crossed.

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ABSTRACT

Intense competition among the six market centers that trade NASDAQ-listed securities has, under decimals, led to development of significant differences in their quoting behavior, execution costs, and information shares. Non-NASDAQ markets contribute sufficiently to the best bid and offer that using only NASDAQ quotes overstates spreads by four cents. ECNs are more different than alike due to differences in depths of their limit order books and trading clienteles. Liquidity seems to be the foremost concern of informed traders, as price discovery for less active stocks occurs on the venues that provide liquidity, whereas for more active stocks informed trades are executed on venues that provide both anonymity and liquidity. We find that market fragmentation causes 14% of NBBOs to be locked or crossed.

In the past several years, changes in U.S. equity markets have caused intensified competition in the market for the NASDAQ-listed securities. In addition to the dealer-operated NASDAQ system, investors now have an opportunity to trade securities on electronic communications networks (ECNs) such as Archipelago and Island, on institution-based matching systems such as Instinet, and on specialist systems at the American Stock Exchange (AMEX) and the Chicago Stock Exchange.[1] As a result, the dealers on the NASDAQ Stock Market compete for order flow not only with each other, but also with a number of ECNs and with market makers from two regional exchanges. This study shows that this interaction may result in more competitive quoting behavior, but does so at the cost of significantly fragmenting order flow and reducing certain venues' execution abilities.

We examine the competitive landscape of the market for NASDAQ-listed securities and investigate how competition under decimals affects trading venues of different types. We seek to answer the following questions. Does fragmentation significantly affect order flow and market quality for NASDAQ-listed securities? How competitive are quotes coming from the various market centers? Are ECNs more different than alike in terms of order flow and trading cost characteristics? Does fragmentation, price discovery, or ECN behavior vary across active and less active stocks or by the size of the trade? In a multi-market setting, are anonymity and liquidity equally important for informed traders?

We find that the nature of competition in this market is different than that previously found for NYSE-listed stocks, in that the primary venue is a much less effective competitor. In the vastly diverse environment of NASDAQ trading, market centers evolve to differentiate from each other in terms of execution costs, trading clienteles, order book characteristics, and market maker behavior. Contrary to the assumptions of Barclay, Hendershott, and McCormick (2003), the primary difference among markets does not lie in the classification into ECNs and market maker-operated venues, but instead is determined by the factors related to each market individually. Our results reveal substantial variation across all markets, including ECNs, in terms of intensity of transacting, ability to provide sufficient inside depth,

[1] Island changed its name to INET ATS, Inc on November 17th, 2003. As this change came after our sample period, we retain the use of the former name. In addition, NASDAQ has proposed to merge with INET, and the NYSE has proposed to merge with Archipelago. These mergers have not yet obtained regulatory approval.

level of trading costs, and informed trading. While in general we confirm the findings of several earlier studies that show that ECNs are cheaper to trade on than NASDAQ, we also show that there is substantial variation across ECNs: trading on Island is considerably cheaper than on the other two ECNs, Archipelago and Instinet. In fact, the data reveals that trading costs differ more among the ECNs than between the ECNs and markets with human intervention.

We suggest that the majority of the differences among the electronic communication networks are caused by differences in depths of their limit order books. As Boehmer (2004) notes, speed of execution is an important dimension of execution quality to traders. Informed traders with time-sensitive information will gravitate towards venues with deeper, more liquid limit order books. If a liquid limit order book is not available, the timeliness or even ability to obtain an execution becomes questionable. Informed traders are therefore more likely to route their orders to the market maker-operated venues, increasing those venues' information shares. Our investigation of price discovery conducted using the vector error correction model (VECM) confirms this argument and shows that the distinction between the ECNs and market makers documented earlier in the literature (e.g., Huang, 2002; Barclay, Hendershott, and McCormick, 2003) is much less clear in contemporary environment of intense competition and order flow fragmentation. In particular, division of the sample into trading activity quintiles allows us to show that for less active stocks the majority of price discovery takes place on the specialist- and dealer-operated venues, whereas informed trading in liquid stocks tends to occur on the ECNs. This result amends several earlier studies (Huang, 2002; Barclay, Hendershott, and McCormick, 2003) that argue that informed traders prefer transacting through the ECNs due to anonymity offered by the networks. We suggest that the switch in price discovery venues that occurs for less active securities is due to the lack on depth of the limit order books of certain ECNs. In particular, we show that Island and Instinet may not always be able to satisfy the traders' demands for liquidity, which causes execution delays and, consequently, cancellations of time-sensitive orders.

The competitive structure of NASDAQ is still relatively unexplored, whereas that of the NYSE is well documented [e.g., Lee (1993), Blume and Goldstein (1997), Bessembinder (2003b), and Lipson

2004)]. In light of the recent shift towards consolidation in the U.S. securities markets, such as announced NYSE-AcraEx and NASDAQ-Instinet mergers, both of these markets' competitive structures merit further examination. Until recently, it has been difficult to study competition for NASDAQ stocks across trading venues and market types due to the absence of relevant data. Fortunately, organizational consolidations and relocations of quote and trade reporting by the major ECNs that occurred in the past several years allow for the examination of the effects of competition and fragmentation within the NASDAQ market system. One of the unique features of our study that differentiates it from the previous analyses of trading in NASDAQ securities is that we are able to distinguish among the three major ECNs: Island, Instinet, and Archipelago, as well as introduce two specialist-operated market centers: the AMEX and Chicago Stock Exchanges.

Overall, the data indicate substantial fragmentation of trade flow in NASDAQ-listed stocks. In our sample, almost half (48.41%) of all trades occur away from NASDAQ, and nearly all of these non-NASDAQ trades take place on one of the three electronic limit order book systems that sustain a high level of competition by posting the best quotes. We find that venues are more likely to execute a trade when they participate in quoting of both sides of the NBBO.

Collectively, our results imply that NASDAQ is not as quote-competitive for NASDAQ-listed securities as the NYSE is for the NYSE-listed stocks. We find that NASDAQ participates in the best quote on at least one side of the market about 90% of the time, which is more than any other market, but is less than the 99% for NYSE as shown in Blume and Goldstein (1997) and Bessembinder (2003b). Furthermore, we show that NASDAQ matches both sides of the NBBO only about half the time and is alone at quoting the best bid or the best ask only 11% of the time, while the results in Bessembinder (2003b) indicate that the NYSE matches both sides of the quote almost 90% of the time, and is three to four times as likely to be alone at the best quote. In addition, in contrast to previous studies that have shown that the NYSE has *lower* effective spreads than its competitors, we find that NASDAQ's effective spreads are the second *highest*.

We partition our sample into four trade size categories that allow us to investigate markets' abilities to accommodate different order sizes and theorize that the NASDAQ dealers' expectations as to the trades' information content are not as monotonic as previous research suggests. According to Huang and Stoll (1996), dealers know their order flow and are frequently able to learn the information embedded in a trade before its execution. Barclay and Warner (1993) and Chakravarty (2001) find support for stealth trading theory by showing that medium-size trades usually lead to more significant price changes than small or large trades. We augment this theory by suggesting that for large trades the benefit of discovering the underlying information is likely to exceed the cost, but for medium-size trades (500-4,999 shares) this cost-benefit relation may be small or even negative. Thus, market makers may consider medium-size trades to be economically infeasible to investigate, yet they may be still uncertain about these trades' information content. As the evidence in this study shows, one solution is for dealers to charge medium-size trades with unexpectedly high trading costs.

As the NASDAQ inter-market structure becomes more competitive and fragmented, non-positive spreads are frequent for NASDAQ-listed securities during continuous trading hours. We find that about 14% of inter-market spreads are either locked or crossed. Although not directly harmful to the market makers' revenues, these episodes may disrupt trading, presenting impediments to market functionality. Specifically, when the NBBO spread becomes non-positive, trading software systems on some venues halt executions until the issue is manually resolved. Non-positive spreads are often blamed on the access fee rebate practices used by the ECNs in order to attract limit orders. However, we find that Island is the only ECN that is able to attract additional trades during the periods of locked and crossed markets.

Overall, we find that in a world of very low trading costs and minimal minimum tick size, fragmentation does affect order flow and market quality, but it affects each market differently. In this highly competitive arena, ECNs pursue different strategies and are therefore are more different than alike; grouping them masks important differences in their behavior. Fragmentation and competitiveness vary across more actively and less actively traded stocks, implying that the availability of different trading mechanisms in a competitive market benefit different securities.

The rest of the paper is organized as follows: Section I provides a brief history of the trading venues, while section II describes the sample. Section III examines issues related to fragmentation and market shares. Section IV describes and analyzes the results on trading costs, and section V examines quote competition and trading activity. Section VI introduces the results on fragmentation through the examination of locked and crossed markets. Section VII analyzes the determinants of order routing, and section VIII concludes.

I. History and Identification of Trading Venues

Trades and quotes for NASDAQ stocks are reported via six different venues: NASDAQ, the American Stock Exchange (AMEX), the Cincinnati Stock Exchange (CSE), the NASD Alternative Display Facility (ADF), the Chicago Stock Exchange (CHX), and the Pacific Stock Exchange (PSE).[2] As a result of increased competitive pressures in the past several years, these six reporting venues underwent transformations that significantly affected their trading and quoting practices and allowed for identification of some of the leading competitors for market making. In particular, by the second quarter of 2003, these changes allowed the identification of quoting and trading activities of the largest electronic limit order books competing for NASDAQ order flow: Island, Instinet, and Archipelago. As a result, disseminated data became more informative. We therefore have chosen the second quarter of 2003 as our sample period, as this is one of the most competitive times during which the data was most informative.

These changes in reporting occurred at various times clustered shortly before our sample period. For example, in March 2002, Island (at the time the largest ECN on NASDAQ) switched reporting of its trades to the Cincinnati Stock Exchange. Routing of the quotes through the CSE followed in October 2002. Island initiated the move, arguing that reporting fees charged by the CSE were more appealing

[2] The Cincinnati Stock Exchange changed its name to National Stock Exchange on November 7, 2003. As this change came after our sample period, we retain the use of the former name.

than the ones assessed by NASDAQ. During our sample period, almost all trades and quotes reported through Cincinnati were coming from the Island ECN.[3]

In October 2002, the National Association of Securities Dealers Inc. (NASD) introduced the Alternative Display Facility (ADF) – a quotation collection, trade comparison, and trade reporting resource. During the time period of this study, Instinet mainly reported its trades and quotes through the ADF and overwhelmingly dominated the venue. On February 9, 2004, Instinet stopped reporting via the ADF, causing the activity on the venue to drop by 99%.[4] Therefore, we assume that virtually all trades and quotes reported on the ADF during this study's time period can be ascribed to Instinet.[5, 6]

In the past several years, Archipelago Exchange developed an extensive alliance with the Pacific Stock Exchange. Archipelago was launched in January 1997 as one of the four original ECNs approved by the SEC. In 2000, Archipelago partnered with the Pacific Exchange, Inc., and in early 2003 the Pacific Exchange began disseminating Archipelago's trades and quotes in NASDAQ-listed stocks. The migration of NASDAQ-listed stocks to the Pacific Exchange started in February 2003 and was completed in early April 2003, making Archipelago the first fully open, electronic exchange to trade all NYSE, AMEX, PCX and NASDAQ-listed securities.[7]

In addition to Island, Instinet, and Archipelago, two other markets, the Chicago Stock Exchange and the American Stock Exchange, participate in quoting and trading of NASDAQ-listed securities. The Chicago Stock Exchange employs a competing specialist system, somewhat similar to the competing dealer system of NASDAQ. Specialists on the American Stock Exchange also post quotes and execute

[3] According to Bonnie Greenberg, Director of Corporate Communications at the Cincinnati Stock Exchange, about 99% of quotes and trades in NASDAQ-listed stocks routed through the CSE were coming from the Island ECN.
[4] We thank Tim McCormick (formerly of NASDAQ) for this information.
[5] Although Island Holding Company and Instinet Group Inc. completed their merger on September 20, 2002, during the second quarter of 2003 (our sample period), Island reported its quotes and trades through the CSE while Instinet's trades and quotes were routed to the ADF.
[6]While virtually all ADF activity during the sample period can be attributed to Instinet, not all Instinet trades and quotes were routed to the ADF. A portion was disseminated through the SuperMontage and merged with the trades and quotes of NASDAQ dealers in TAQ. We, therefore, use caution in interpreting the results obtained for NASDAQ further in the paper.
[7] Archipelago finished the migration of NASDAQ-listed stocks to the PSE on April 11th, 2003. To avoid possible anomalies caused by this transition, we ran our tests for a May-June sample period as well as April-May-June sample period. Analyses of the former and the latter delivered quantitatively similar results. We present the results for the three-month period.

trades in NASDAQ-listed stocks. AMEX was integrated into the NASD system after its acquisition in 1998; however it remains a largely self-regulated organization with the NASD Office of the Chairman responsible for strategic development and policy initiatives. Although technically a part of NASD, AMEX still does not make its quotes available electronically to SuperMontage participants, and, according to Shkilko, Van Ness, and Van Ness (2005), sometimes causes connectivity problems.

II. Sample

The study considers a sample of 100 NASDAQ-listed common stocks comprising the NASDAQ-100 market index (QQQ) in the second quarter of 2003 (April, May and June 2003).[8] We chose to investigate the second quarter of 2003 for a variety of reasons. This time period covers a period of intense competition across market centers. In addition, in contrast to the sample period used in other studies such as Huang (2002) or Barclay, Hendershott, and McCormick (2003), this time period covers trading in decimals, providing an opportunity to examine competition across markets during a time of very low trading costs.

The data for the study are extracted from (i) the Trade and Quote (TAQ) database provided by the NYSE and (ii) the Dash-5 database (reported in accordance with SEC Rule 11Ac1-5) obtained from Transaction Auditing Group, Inc. and Instinet Group, Inc., and (iii) the CRSP database. In order to remove issues related to after hours trading, studied by, among others, Barclay and Hendershott (2003), the sample obtained from TAQ is restricted to include only quotes and trades that occur during regular trading hours (9:30 a.m. to 4:00 p.m., EST). Additionally, we apply filters to the TAQ data to remove observations that could be subject to errors. In particular, trades and quotes are omitted if the TAQ database indicates that they are out of time sequence or involve either an error or a correction. Quotes are

[8] USA Networks (ticker: USAI) formed a joint venture with Vivendi Universal on May 7, 2003. A joint venture was further spun off to create USA Interactive (ticker: IACI). This stock is excluded from the sample after May 7, to account for possible instability related to the aforementioned activity. We perform our tests using two samples: A – with USAI until May 7 and B – without USAI. The results appear qualitatively identical. The findings reported further in this study include USAI.

also omitted if either the offer or the bid price is recorded in the database as equal to or less than zero. Finally, trades are omitted if the price or volume is equal to or less than zero.

III. Fragmentation and Market Share

We first examine the extent of fragmentation by analyzing the differences in market share across the primary market (NASDAQ), the other dealer/specialist markets, and the ECNs. Table I provides market share data: Panel A contains venues' market shares as a percentage of trades according to trade size; panel B – as a percentage of trading volume; and panel C – as a percentage of trade volume by trading activity quintile. NASDAQ executes only 51.59% of trades in the sample. The three electronic limit order book systems – Instinet, Island, and Archipelago – complete 11.30%, 17.12%, and 19.31% of the trades, respectively, while the two specialist systems, AMEX and the Chicago Stock Exchange, execute a mere total of 0.68%. It appears that the AMEX and Chicago Stock Exchange do not have substantial influence on the market in NASDAQ-listed securities, since their share of trade executions is so small. This conjecture is further explored in later tables.

We divide the sample into four trade size groups: small trades (less than 500 shares); trades from 500 to 4,999 shares; trades from 5,000 to 9,999 shares; and large trades – those exceeding 10,000 shares. NASDAQ's share of trading volume in large trades is 91.47%, while its share in small trades is only 48.34% (Table 1, Panel B). The pattern is also observed for AMEX and Chicago – the two specialist systems. Conversely, the three electronic limit order book systems – Island, Instinet, and Archipelago – exhibit decreasing patterns of share volume from small to large trade sizes. Similar results are found for shares of sample trades (Panel A). Paired *t*-tests generally confirm statistical significance of the aforementioned differences in the market shares. These results are consistent with those of Barclay, Hendershott, and McCormick (2003) who show that ECNs tend to execute smaller trades than NASDAQ market makers. Our finding that these results hold true not only for NASDAQ, but also for the competing dealer/specialist systems of AMEX and Chicago, indicates that execution of larger trades is not just a feature of NASDAQ dealers specifically, but of dealer or specialist systems in general.

Panel C presents results for an alternative sample division by trading activity quintiles. We break the sample into five groups according to the stocks' three-month trading volume, where quintile one is the most active, and quintile five is the least active. Although our sample stocks are "the most active" on NASDAQ, their trading volumes vary substantially: for example, 3.8 billion shares of Microsoft (the most active stock) were traded during the three-month sample period, while only 26.6 million shares of C.H. Robinson Worldwide, Inc. (the least active stock) changed hands during the period. (Sample statistics on the quintiles are provided in the Appendix.) Interestingly, although we would expect ECNs to be more active in securities with higher trading volumes, the statistics in Panel C do not show any consistent patterns in market centers' shares among different quintiles.

Table I also shows that, while Island's and Instinet's shares of trading volume drop by about the same amount between the 100-499 and 500-4,999 categories (4.47% and 4.43%, respectively), Archipelago's share falls only by 2.12%. We suggest that, for these trade sizes, the limit order book on Archipelago may be deeper and thus may give the ECN the needed capacity to handle trades in the second size category.[9] To validate this conjecture, we perform an investigation of order executions and cancellations on the three ECNs. For an order to be executed by an ECN, a market or a limit order (or several orders) with an acceptable price has to be pending on the other side of the book. If the number and/or depth of these pending orders are/is volatile on a particular ECN, two possible scenarios may evolve. First, since traders are likely to be aware of this peculiarity of the ECN, fewer orders will be routed to it. Second, as suggested in Hasbrouck and Saar (2005), the fleeting orders that are submitted to the network are likely to be cancelled more often, as the waiting time for execution (especially for the limit orders) may exceed traders' initial expectations.

[9] This suggestion is confirmed by the regression results in Table VIII, in which it is shown that although trade size negatively affects ECNs' chances of executing an order, this relationship is not as economically strong for Archipelago as it is for Island and Instinet.

Empirical investigation of the first scenario requires a more sophisticated dataset than is available. In particular, we would need data on traders' decision making prior to submitting an order to investigate its validity. Although we are unable to empirically evaluate the first suggestion, we use Dash-5 data on orders to examine the second one. Table II contains the number of market and marketable limit orders executed on the networks as a percentage of all covered orders of the same type.[10] The results show that, in all but one size category, Archipelago executes more orders before cancellation than Island and Instinet. Therefore, we conjecture that Archipelago's limit order book is, on average, deeper and more stable than those of the two rival ECNs.

Collectively, these results indicate that the market for NASDAQ stocks is much more fragmented than that found previously for NYSE-listed securities, and that these market shares vary both by trade size and by trading activity level of the stock. We also find that different ECNs provide different services from one another, both based on the trading activity of the underlying stock and on the size of the incoming trade, due, in part, to differences in the depth of their limit order books.

IV. Trading Costs, Profits, and Price Discovery

With NASDAQ garnering around 50% of the total order flow in the sample stocks, and the remaining 50% of trading occurring on other venues, the question remains as to how much these other venues compete on the basis of price and execution quality. To answer this question, we use effective

[10] Island did not accept market orders during the sample period; therefore, we only investigate marketable limit orders for this ECN.

half-spread as a measure of trade-based execution costs.[11] In the analysis of trade-based execution cost measures, we use only the NBBO quotes in which the NBBO spread is greater than zero.[12]

The effective half-spread measures how close the trade price comes to the quotation midpoint, a conventional proxy for the real value of the stock. To compute the effective half-spread measure at time *t*, we reconstruct the National Best Bid and Offer (NBBO) at time *t* across all venues, and subtract it from the trade price of a trade executed on one of our six sample trading venues at time *t*. Thus, the effective half-spread for security *i* at time *t* is defined as:

$$\textit{Effective Half-Spread}_{i,t} = I_{i,t}\left(P_{i,t} - M_{i,t}\right), \text{ where}$$

I_{it} is an indicator variable that equals one for the customer-initiated buys and negative one for the customer-initiated sells, P_{it} is a trade price, and M_{it} is an NBBO midpoint for stock *i* at time *t*. Similar to Bessembinder (2003b), we designate trades as customer buys and sells using the algorithm described by Ellis, Michaely, and O'Hara (2000).

Microstructure studies [e.g., Huang (2002) and Barclay, Hendershott, and McCormick (2003)] argue that, due to the anonymity of trading through ECNs, these networks execute more informed trades and contribute more to price discovery than the venues that employ market makers. We add to these findings by suggesting that under conditions of increased market fragmentation that characterize our sample, order execution quality and speed could become issues of foremost importance to informed traders.[13] In particular, with Island's and Instinet's limit order books being less deep than that of Archipelago's, an informed trader with time-sensitive information might be willing to submit his order to a venue that provides less anonymity, but faster executions (e.g., Archipelago or NASDAQ).

[11] As noted by Blume and Goldstein (1992), Lee (1993), and Petersen and Fialkowski (1994), quoted spreads are a poor proxy for the actual transaction costs faced by investors, because many large trades occur outside the spread, while many small trades occur within the spread. The situation is exacerbated by the sub-penny pricing actively applied by some exchanges (the practice is especially widespread on Island, Instinet, and NASDAQ). Sub-penny pricing is discussed later in this section.

[12] By restricting the NBBO spreads to be positive, we avoid the many instances in which the inter-market is crossed (best bid quote is greater than the best ask quote) or locked (bid and ask are identical). Section VI presents more evidence on locked and crossed markets.

[13] Boehmer (2004) notes that execution quality is multidimensional and that speed of execution is an important consideration for traders when choosing execution venues and order sizes.

Table III reports the effective spreads for each trading venue in Panels A (by trade size) and B (by volume quintile). Panel C, in turn, contains results on the information shares calculated via the Vector Error Correction Model (VECM) of transaction prices described in detail by Hasbrouck (1995), Huang (2002), Harris, McInish, and Wood (2002), Hendershott and Jones (2005), and Cao, Hansch, and Wang (2005). By construction, the VECM approach is unable to provide single-figure determinants of information shares. Panel C therefore contains the upper and the lower bounds of information share estimates for each exchange in the sample. Finally, for all exchanges, we compute the percentage of orders that are price improved and percentage of orders executed outside the NBBO (Panel D). An order is considered to be completed with price improvement, if price of execution is lower than the NBBO ask for customer buys and is higher than the NBBO bid for customer sells. An order is executed outside the NBBO when the price of execution is higher (lower) than the NBBO ask (bid) price for customer buys (sells).

Overall, the effective half-spread is lower on the electronic limit order book markets and higher on the dealer/specialist markets; however, we find substantial variation of trading costs not only *between* but also *within* these two market types. In particular, the effective half-spread for Island averages 0.71 cents per share, followed by Instinet with 0.84, and Archipelago with 0.93 cents. As for the dealer/specialist group, the effective half-spread averages 1.04 cents on the Chicago Stock Exchange, 1.10 cents on NASDAQ, and 1.90 cents on AMEX. Note that the difference within the two groups is at times as large as or even larger than that across groups: for instance, the difference in execution costs of a round lot (one hundred shares) between Island and Archipelago is, on average, twenty-two cents, which is larger than the seventeen cents difference between Archipelago and NASDAQ. Thus, although ECNs indeed provide the benefit of cheaper trading, the differences in costs within the ECN group appear to be as economically significant for the trading public as those across market types.

Quantitatively, our results appear quite striking when compared to those of the earlier studies. For instance, Bessembinder (2003a) examines a sample of the NYSE- and NASDAQ-listed stocks and finds effective half-spreads of, respectively, 4.93 and 9.36 cents. Similarly, Bessembinder (2003b), in an investigation of execution costs for one hundred large-capitalization NYSE-listed securities in the 1/16th minimum tick size environment finds that effective half-spreads range from 3.67 to 4.63 cents.[14] Although our results are not directly comparable, it is apparent that trading costs have significantly decreased over a short time period. We attribute this discovery to the consequences of decimalization and to the increased competition from alternative trading venues, namely ECNs. Although beneficial to those who submit small market orders, this drastic reduction in execution costs has diminished dealers' and specialists' rents.

Trading costs dynamics aside, we also find substantial variation in trading costs across order sizes. NASDAQ, Archipelago, Island, and Instinet generally show a drop in effective half-spreads as order size increases from the smallest category (100 to 499 shares) to the largest (over 10,000 shares), although these transitions are not uniform. Island and NASDAQ experience a substantial increase in effective half-spreads (58% and 44%, respectively) between the first and second (501 to 5,000 shares) size categories and then about a 50% drop to the third category (5,001 to 9,999 shares). Instinet and Archipelago differ from Island in that they do not show such a sizeable increase between the first two size categories (in fact, the effective spread on Instinet drops by 2.4%) and show a smaller drop from second to the third categories. Thus, opposite to the results of Barclay, Hendershott, and McCormick (2003), we find that spreads get smaller, not larger, as trade size increases, though the increase is not uniform.[15] We also find substantial variation across ECNs in terms of their effective half-spreads in different trade size categories.

Our findings in Panel A necessitate further discussion. Huang and Stoll (1996) suggest that NASDAQ dealers, generally, know their order flow. We believe that, taken literally, this notion is true for trades of large sizes, while for medium-sized trades, it is more costly to establish the identity of the counterparty, and therefore market makers' confidence on whether a medium-size order is informed is

[14] Bessembinder (2003a) and Bessembinder (2003b) consider, respectively, 1998 and 2000 sample periods prior to decimalization.
[15] Barclay, Hendershott, and McCormick (2003) use only three size categories: less than or equal to 1,000 shares, 1,001 to 9,999 shares; and 10,000 shares and over. Our four-category division reveals substantial non-linear variation in the smaller and medium categories that is masked by using coarser categories.

questionable. Lee and Radhakrishna (2000) note that, for orders greater than $100,000, there is only a one percent chance that a trade has retail participants.[16] Using this argument and taking into account that the average NASDAQ-100 security is priced at $27.45 during the sample period, we conjecture that market makers are more or less certain that trades larger than 3,600 (≈ $100,000 / 27.45) shares are informed. There is, therefore, a grey area; in which not too small (more than 499), but not too large (less than 3,600 shares) orders fall. It is not always clear from merely observing trade size whether the opposite party is informed or not. The situation is exacerbated by the fact that these trades are still relatively small, and the dealers' opportunity cost of finding out trade origination may be prohibitive. Given that such trades end up in the 500 to 4,999-share group, higher trading costs in this size category are consistent with the dealers' trying to account for the uncertainty regarding the trades' information content and with the stealth trading hypothesis of Barclay and Warner (1993).

The story is considerably different for ECNs, although it leads to similar results. These computerized trade-matching networks derive profits from membership and trading fees; therefore, they neither deliberately originate spreads, nor purposefully affect spread magnitudes. In addition, private information possessed by certain traders should not affect ECNs' earnings directly. For the most part, the cost of executing a customer buy (sell) order on an ECN depends on the amount of liquidity the network currently carries on the opposite side of the market. This liquidity is represented by the number and depth of market and limit orders submitted for execution. While small market orders do not require substantial liquidity and are usually not difficult to execute, large orders may encounter problems. If the inside depth is not substantial, a large order may have to be split into smaller trades to be completed. For a large order, A, to be executed on an ECN and to be recorded as a large trade, another order, B, at least as large as A, needs to be awaiting execution on the other side of the market. The odds of two such large orders being submitted to an ECN at the same time are rather small; however, they are likely to increase with the

[16] Lee and Radhakrishna (2000) conduct their study using the TORQ database distributed by the NYSE for three months in 1991. Allowing for inflation, we expect their results to suffer from a downward bias, if applied to current data. Nonetheless, in order to add a degree of conservatism to our results, we use the $100,000 figure.

trading volume.[17] As shown by Barclay, Hendershott, and McCormick (2003), volume in the past 15 minutes negatively affects the effective half-spread; hence, the lower spreads for large trade size categories. One caveat to the above argument is that effective half-spreads increase in the second size category on Island and Archipelago. One possibility consistent with this result is that this category captures parts of those market orders that are large enough to consume substantial depth and are, therefore, split in the course of execution. The remnants of these orders end up being executed against limit orders that do not initially appear on the inside, at prices that are further away from the existent best quotes.[18] Interestingly, an increase in trading costs from the first size category to the second does not appear on Instinet. This phenomenon may be due to Instinet's lower trading volume, which implies lower trading frequency and less frequent changes in depth. On Island and Archipelago, trades above certain sizes may be too large to be executed in one transaction: due to high trading frequency, depth may change substantially from the time of trade decision to the time of execution. On Instinet, however, large trades have a better chance of being executed against the inside depth.

The statistics for effective spreads in Panel B display more of a pattern as compared to the ones discussed earlier for different trade sizes: trading costs on all venues with the exception of AMEX increase monotonously as we move from the most active to the least active stocks in the sample. Such an increase in costs is not surprising, considering higher inventory and adverse selection costs market makers incur due to relatively infrequent trading in low-volume quintiles. On the ECNs, higher trading costs for less active stocks may be attributed to lower limit order activity, and hence liquidity.

The VECM results on upper bounds presented in Panel C reveal that NASDAQ, Chicago, and AMEX possess the highest information shares. The ECNs' shares are lower and generally less dispersed, indicating that, for some stocks in our sample, the majority of price discovery happens via the market

[17] We conduct correlation analysis of occurrences of large (more than 3,600 shares) trades and cumulative trading volume in the fifteen minutes preceding these large trades Our results indicate positive correlation.

[18] A large order, A, has a better chance of being executed against a large limit order, B, that is not on the inside than against a large order, C, on the inside. As soon as the order C appears on the inside, it starts being consumed by incoming smaller orders, so that the chances of such an inside order being large at the time of execution against another large order are smaller than for the limit orders that are not on the inside (therefore, preserving their integrity).

maker venues, while for some, information revelation still occurs through the ECNs. To investigate this suggestion, we conduct the VECM analysis for volume quintiles. As Panel C and Figure 1 show, on market maker venues, the share of informed trading increases as one moves to less frequently traded stocks. On the ECNs, the pattern is different, with information shares falling as we move to lower volume quintiles. For more liquid stocks, ECNs are able to provide a relatively safe harbor for informed traders to execute their orders. For such stocks, the ECNs' anonymity is supplemented by liquidity, which makes the networks attractive. In lower trading volume quintiles, however, ECN liquidity is insufficient, and informed trading shifts to the market maker venues. The fact that Archipelago's information share is higher than those of the other two ECNs confirms our earlier conjecture that informed traders avoid trading through Instinet and Island due to the lower depths of the limit order books of the two ECNs. Overall, evidence presented in Panel C contradicts earlier findings on price discovery on dealer and electronic markets and confirms our earlier suggestion about the partial shift of price discovery from the ECNs to the market makers due to potential execution delays on the former and differential depths of the limit order books.

Panel D of Table III reports the percentage of trades executed at prices within the best quotes. All exchanges provide their customers with substantial price improvement: the percentage share of trades executed at prices better than the contemporary quotes ranges from 54.27% on Island to about 10% on Chicago. Although these results seem quite impressive, a closer look at the execution prices reveals that high degrees of price improvement are deceptive, as they are primarily attributable to the sub-penny pricing and rounded-to-a-penny reporting of quotes. TAQ reports bid and ask quotes rounded to the nearest penny, i.e. a XX.XXY quote is reported as XX.XX if $Y < 5$ and as XX.XX + 0.01 if $Y \geq 5$. Meanwhile, trades are reported at the actual prices, so, at times, what appears to be a high level of price improvement is, in fact, caused by the crudeness of the measure of what is getting improved.

Overall, our findings indicate that there is substantial variation across different ECNs and different dealer/specialist systems. Similar to previous studies, we find that ECNs tend to have lower costs than dealers/specialists. Nonetheless, we find substantial variation across ECNs and a lack of consistency across trade sizes in terms of execution costs. Insufficient inside depth on the ECNs makes informed traders willing to shift information-motivated trades away from the networks depending on the relative level of trading activity in the stock.

V. Quote Competition and Trade Execution

In order to measure quote-based competition between the trading venues, we examine the extent of the exchanges' participation in NBBO formation. We differentiate between the following states of competition on quotes: *at the inside bid and/or ask*, when an exchange participates in formation of one or both sides of the NBBO; *at both inside bid and ask*, when a venue participates in forming of both sides of the NBBO potentially along with the other market centers; *alone at inside ask (bid)*, when an exchange forms an ask (bid) side of the NBBO by itself; and *alone at both bid and ask*, when a market center forms the entire NBBO by itself. Table IV shows the percentage of time (Panel A) markets spend in each of the states and percentage of trades (Panel B) executed in each of those states. The most active quoting venue, NASDAQ, is participating in the NBBO formation 89.92% of the time, with 86.52% of trades executed during these periods. The electronic limit order book systems, especially Instinet and Archipelago, contribute a great deal of competition to the NBBO formation: they are on either or both sides 85.25% and 81.86% of the time, respectively. Island's participation is lower – it is competitive only slightly over half the time. Recall that our results in Table II imply that Island has lower inside depth than the other two ECNs. This characteristic of Island's limit order book together with the high trading frequency results in the venue's less active participation in the NBBO formation, as the smaller depth of the inside limit orders is quickly consumed by incoming trades.

Quoting activity of the market centers falls quite dramatically when it comes to forming the entire NBBO. NASDAQ is still the leader, determining the inside quotes 50.24% of the time, while participation of the rest of the market centers ranges from less than 1% to 24.18%. These results expose an important methodological issue for future researchers: when computing the inside quotes for NASDAQ-listed securities, it is erroneous to use only the quotations coming from NASDAQ itself (in

TAQ, quotes with an exchange denoted by "T"). This approach will deliver the correct inside quotes in only 50.24% of the cases and is thus prone to overestimate the quoted spread. In fact, on average the NBBO spread is four cents smaller than the NASDAQ-originated spreads, with the difference statistically significant at 0.01 level.[19] The rest of Table IV shows that a high level of quote-based competition exists in the market for NASDAQ-listed stocks and also that this competition is very acute: none of the exchanges forms the NBBO alone more than 1% of the time.

Generally, orders are directed to a market maker based on the best price. If several market makers post identical quotes, a trade is to be routed according to time priority. Our results in Table IV show that NASDAQ quotes have time priority 52.56% and 50.38% of the time, respectively, for the ask and bid in the NBBOs where NASDAQ participates. Time priority is not as pronounced for ECNs, since their quotes are more frequently consumed by incoming orders. Even if a new quote that matches the NBBO is posted on an ECN just after an older one that has been consumed by an order execution, this new quote does not have price priority unless no other exchange has identical quotes outstanding. Panel D of Table IV studies quote submission interaction among market centers relative to quote-posting activities of each venue. For instance, Island and Instinet match the existing NBBO with, respectively, 9.91% and 11.61% of their quotations. Interestingly, the results show that none of the venues exhibits any noticeable quote improvement features: all market centers participate in quote improvement with 2-4% of their quotes. Although similar in quote improvement, the exchanges show a quite vivid pattern in being late with quote downgrades: AMEX and Chicago are very often slow with changing their quotes with 10.49% and 21.88% of quotes, respectively, left alone at the NBBO.

Panel E reports statistics similar to those in Panel D, however not as a percentage of quotes posted by each venue, but as a percentage of similar cases (match, improve, left alone) across all six market centers. The results reveal that Archipelago posts the most matching quotes (42.53%), followed by Instinet (35.24%), and NASDAQ (29.97%). Archipelago is also responsible for 51.83% of quote

[19] Using only the quotes with the designation "T" in TAQ will thus overstate the spreads for NASDAQ-listed stocks by an average of four cents.

improvements, with NASDAQ improving a smaller share of 42.71%. The results of Panels D and E show that, although certain market centers have highly visible individual behavior (e.g., AMEX and Chicago are the slowest to abandon outstanding NBBO quotes), it is the markets with not so vivid patterns that determine the overall picture.

Next, we examine percentage of a market's volume conditional on its quotes (Table V). Sample trades are categorized by the venue of completion: for each trade, the location of the quote relative to the NBBO is determined. Panel A presents the results for all trades and reveals the existence of two distinct groups of markets that differ by the position of their quotes relative to the NBBO when attracting orders. While NASDAQ and the ECNs obtain the majority of their order flow when posting the best quotes, AMEX and Chicago show an entirely different pattern: most of their executions occur when the exchanges are not posting the inside quotes. The results on AMEX and Chicago are consistent with the preferencing and internalization argument of Huang and Stoll (1996) and a higher percentage of larger, perhaps institutional, orders executing on the two exchanges.

Interestingly, 75.59% of NASDAQ trades are executed during the periods when NASDAQ quotes both sides of the NBBO. From Table IV, these periods only account for 55.87% (=50.24/89.92) of the venue's inside-forming activity. A similar relationship is observed for the ECNs. For instance, Island executes 57.27% of its trades during the period that covers just 24.93% of the time the ECN participates in quoting. The results for Instinet and Archipelago show that they also execute orders more actively when present at both sides of NBBO: 72.55% and 71.12% of trades during the 40.09% and 41.10% of the overall participation time, respectively for Instinet and Archipelago. These findings indicate that not only being at the inside determines whether an ECN gets a trade, but also the trading itself directly influences the position of the quotes ECNs submit to the montage. For instance, during the periods of higher volume caused by aggressive submissions of limit orders, the inside quotes are likely to converge, as noted in Peterson and Sirri (2002). In these situations, it may seem as if quoting at the inside increases the ECN's order inflow, while, in fact, the increased order flow narrows the inside spread. For NASDAQ, the scarcity of trading during the periods when the dealers do not quote the entire NBBO could be attributed to investors' reluctance to trade with a dealer who may possess information about a stock that causes him/her not to be willing to quote both sides.[20]

Another noteworthy finding is the high proportion of trades executed by ECNs when not at the inside. As stated earlier, due to the occasional thinness of the inside depth on ECNs, especially Island, large market orders (often the ones in the 500-4,999 trade size category) are frequently broken up and executed at prices that do not match the inside quotes. We attribute a relatively high degree of executions when an ECN is not posting the best quotes to this phenomenon. The largest proportion of executions when not posting the inside quotes is in the second trade-size category, the one to which we earlier ascribed the majority of the broken up trades. Note also that the share of trades executed on the AMEX when the venue is not posting the best quotes increases with the trade size, which is consistent with our earlier conjecture that a large portion of AMEX's order flow may be preferenced. On the ECNs, the share of trades completed when the networks post the inside quotes is rising with the trades size, adding credence to our earlier speculation that large market orders are only routed to the ECNs when there is substantial inside depth for them to be completed at the NBBO prices.[21]

Overall, these results indicate that the nature of the bid and ask quotes on each ECN differ, and that these differences in quotes result in different order flows. These variations are notable: in general, Instinet looks more like NASDAQ than it does Island, both on overall quoting behavior and on order flow conditional on these quotes. This result is somewhat surprising, given the INET merger, but may help explain the proposed NASDAQ-Instinet combination. The natural variation in ECNs limit order books and strategies likely result from traders using the different ECNs for different reasons at different times based on limit order book depth, anonymity, and execution speed.

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[20] A dealer also might not be willing to quote both sides because of inventory considerations. Nonetheless, when traders cannot be sure about the dealer's motives, they may prefer not to trade at all.

[21] We conduct an analysis similar to that of Table V for the sample subdivided into trading activity quintiles. The results are qualitatively similar to those discussed above and are available upon request.

VI. Locked and Crossed Markets

The quote competition across these markets results in an interesting and unfortunately negative by-product, i.e., frequent locked and/or crossed markets. The National Best Bid and Offer (NBBO) quotes are not provided by the TAQ database, making it necessary to reconstruct them using the quotes from the six exchanges. As result of such a reconstruction, we find that 12.09% of all spreads are zero and 2.22% are negative. The data in Table VI show that non-positive spreads are not attributable to any particular set of days and are fairly consistent across the three sample months (panel A) as well as on a daily basis (panel B contains the daily results for June).

This phenomenon is seemingly inconsistent with theories proclaiming spreads to be a natural compensation to the market makers for liquidity and immediacy (Demsetz, 1968) or for the execution, inventory, and adverse selection costs they encounter (Stoll, 2000). The Security Traders Association (STA) acknowledges that locked and crossed markets are an issue on NASDAQ.

The problem of locked or crossed markets is mostly blamed on ECN access fee rebates, as discussed in Clary (2003). In their constant quest for liquidity, ECNs reward the liquidity-providing limit orders with rebates. Market orders, on the other hand, do not get rebates and are charged the entire fee amount. Thus, traders executing their orders through ECNs are often tempted to submit a limit ask (bid) order at the outstanding bid (ask) NBBO price and get a rebate after the trade completion. If the locking bid and the ask quotes on different ECNs are from limit order traders looking to generate rebates, the market may remained locked. In addition, Island ECN does not accept market orders, but instead accepts marketable limit orders, which may lock the NBBO when spreads are tight.

Even though we find that the spreads are crossed or locked in more than 14% of the cases, there is no evidence that the markets are locked for extended periods of time. An examination of NBBO quotes (not tabulated) shows that although markets lock or cross quite frequently (about once every minute), they do so for short periods of time (no longer than 10 seconds). This is consistent with rebates being a cause of non-positive spreads. In fact, if a zero spread is created by a limit order posting on one of the ECNs, the problem should be resolved as soon as this limit order is executed. Since computer trading systems often are programmed to halt executions during non-positive spread periods, and trades have to be completed manually, it is in the interest of all market participants to promptly unlock (uncross) the NBBO spread.

We next determine which exchanges are affected by the non-positive spread occurrences. We conduct an analysis similar to the one presented in Table IV to investigate the exchanges' quote participation during locked and crossed markets. Our findings are provided in Table VII, where Panel A contains the results for zero spreads (locked markets), and Panel B – for negative spreads (crossed markets). The data reveal that quotes of NASDAQ and Instinet are affected by the locked market instances the most, respectively, 7.53% and 7.42% of trading time (8.37% and 8.70% of the overall time the venues participate in forming of the NBBO). Archipelago and Island participate in quoting during the zero-spreads periods a little less, respectively, 5.74% and 4.41% of trading time (7.01% and 8.40% of the time these markets quote). Quoting activity of AMEX is affected by locked markets more often than that of the other venues, 11.17% (=3.45/30.90) of the market's participation in the NBBO occurs during the periods of zero spreads.

Generally, software employed by the market centers to facilitate trading is designed to avoid non-positive spreads. In the simplest case, this software is supposed to prevent a potentially locking or crossing quote from being posted by a market participant. Our results show, however, that these systems do not always perform as intended. Note, for instance, that on Instinet 0.28% of zero and 0.06% of negative spreads (time-weighted) occur when the venue participates in forming both sides of the NBBO. In these instances, Instinet locks and crosses the NBBO without interaction with the other venues. Some evidence of creating the zero-spread situations is also found on ArcaEx: 0.01% of the trading time the exchange posts identical quotes on both sides of the market.

We show that NASDAQ and ECNs are affected by locked markets to about the same degree. A slightly different pattern emerges for crossed markets: negative spreads occur most often when Chicago is participating in the formation of the NBBO. The exchange participates in negative spreads 2.57% of the total quoting time or 61.05% of time it quotes at the NBBO.

Collectively, the relatively high proportion of locked and crossed markets indicates a high degree of quote competition across these markets. However, this high proportion also indicates a lack of integration across these markets, demonstrating that one of the costs of this fragmentation is increased frequency of locked and/or crossed markets, thereby reducing market quality.

VII. Determinants of Trade Executions

Only 51.59% of our sample trades are executed on NASDAQ, while 48.41% are captured by the other five market centers. Although the survey of quoting activity presented in the previous sections provides insights on quote competition, we further examine fragmentation, price discovery, quote competition, and order flow characteristics across markets with a multiple logistic regression model to study the determinants of trade execution. We also examine how immediately previous liquidity affects competition for order flow across these markets to examine the effects of liquidity, speed, and informed trading on non-NASDAQ venues.

We use a multinomial logistic regression specification for an unordered response, where the dependent variable is the exchange where the trade occurs. Trades are divided into customer buys and sells and examined separately. The regression outcome for both groups is similar; therefore, we only provide results for customer buys.[22] A vector of regressors includes the following: dummy variables capturing whether an exchange is at the best bid or ask (six variables, one for each venue, for best bid; and six – for best ask), aggregate order imbalance on all six markets, number of trades in the preceding 10 minutes, trade size, and a dummy variable indicating if the market is locked or crossed at the time of trade execution. The model accounts for fixed effects and non-spherical errors by allowing for clustering across stocks and employing the Huber-White estimator.

The following relations between the dependent variable and the regressors specified above are expected. If exchange A posts an *ask* quote at the NBBO, a customer buy trade should have a higher probability of being executed on that exchange. On the other hand, inside *ask* quotes for all exchanges

[22] The results for customer sells is available from the authors upon request.

other than A should decrease the probability of a trade being executed on A, indicating competition among trading venues through posting of the best quotes.

An expected relationship between the inside *bid* quotes and customer buy orders is dichotomous. On one hand, a *bid* quote should not affect the customer buy trade execution, so the relation between an exchange's posting of a bid quote at NBBO and the probability of getting a trade by that exchange should be zero. However, according to the scenario mentioned earlier, traders may avoid dealer/specialist venues that post inside quotes only on one side, due to fear of being on the wrong side of the market, while the probability of ECNs being on both sides of the NBBO is proportional to the trading volume. If this reasoning holds true, we expect a positive relationship between the aforementioned variables.

The *order imbalance* regressor is constructed based on the accumulated difference since the beginning of a trading day between customer buy and customer sell trades (Bessembinder, 2003b). Positive order imbalance indicates that more securities have been sold than bought from the beginning of the day. Generally, we expect a buying or a selling trend to continue, so the coefficient for this variable is expected to be positive for all trading venues.

We expect the relationship between the *number of trades during the immediately preceding ten minutes* and the dependent variable to be positive if non-NASDAQ venues are more likely to execute a trade when the market is liquid. A positive relationship would also be consistent with ECNs being able to post better quotes when trading is more intensive. Alternatively, the relationship could be negative if a market is trying to avoid informed traders, the presence of which may be indicated by increased trading volume.

The outcome of the multiple logistic regression is provided in Table VIII. The model delivers results in the form of marginal effects that are reported *relative to NASDAQ*. For instance, Island's chances of executing a customer buy are 8.38% higher that NASDAQ's, *ceteris paribus*, if Island's ask quote is at the NBBO. Similarly, if the market is crossed or locked, Island's chances of executing a buy trade are 6.07% higher that those of NASDAQ.

The results demonstrate that rival markets, especially ECNs, are generally capable of competing for trades by posting competitive quotes. Archipelago's and Instinet's chances of executing a trade exceed those of NASDAQ by, respectively, 10.17% and 2.76% if the ECNs are at the best ask. While Island and Archipelago are very quote-competitive, Instinet's executions do not drastically increase as a result of posting the best quotes. We attribute this result to the lower frequency of Instinet's order execution mentioned earlier. With lower execution rates, the ECN loses one of its major advantages – speed. Also, since informed orders are easier to hide when the volume is higher as noted in Admati and Pfleiderer (1988), informed traders are likely to prefer the other two ECNs. The results also show that AMEX and Chicago are not quite competitive with NASDAQ in terms of posting the best quotes. AMEX and Chicago likely receive most of their order flow due to the preferential agreements, making them unwilling to compete on quotes. Posting of the inside quotes by the ECNs increases their chances of additional executions by a larger percent than posting of the inside quotes by NASDAQ decreases these chances. Notably, NASDAQ's presence at the NBBO does not change, or changes only slightly, the chances of an order executing by AMEX or Chicago.

In some instances we find that a market may get a trade if another market posts the best quote. The most vivid example of this phenomenon is the 2.68% increase of Archipelago's chances of executing a trade when Instinet's ask quote is at the NBBO. This one-sided symbiosis is unexpected; however we hypothesize that these trades might result from re-routing of some trades to ArcaEx when Instinet has a queue of orders waiting to be executed. The infrequent cases of symbiosis and preferencing aside, we generally find that the exchanges compete against each other on the basis of quotes.

Table VIII also presents evidence that by posting the best *bid*, exchanges are able to attract additional customer *buys*. This confirms our reasoning that traders prefer to transact with market makers who quote both sides of the NBBO. Order imbalance has an expected positive sign, and coefficients for all exchanges are positive and significant: if the public has been buying a security since the open, an additional customer buy is more probable. As predicted, increases in trading volume in the previous 10 minutes make the ECNs more competitive and raise their chances of executing a trade. If trading volume in the last 10 minutes is higher than the average volume by 10 trades, the chances of execution by Island, Instinet, and Archipelago become higher than those of NASDAQ by 2.9%, 2.3%, and 11.1%, respectively. Coefficients for the trade size variable are in line with the discussion of ECNs' problems providing sufficient liquidity for large trades. The results indicate that a 100-share increase in trade size lowers the chances of trading on Island, Instinet, and Archipelago by 1.81%, 1.73%, and 0.70%, respectively. Executions on AMEX and Chicago either do not seem to be affected or are slightly positively related to volume, again confirming our hypothesis of preferential agreements between the market makers on these two venues and their clients. The non-positive spread variable appears significant and positive only for Island; for all other venues, the fact that the NBBO spread is not positive does not seem to affect the likelihood of trade executions. Although not the only market responsible for locks and crosses, Island is the only one that benefits from the phenomenon, most likely due to executions of marketable limit orders.

Overall, we find significant differences in trade execution across markets. These differences are based on quoting characteristics, speed of execution, and liquidity. We again find notable differences across ECNs as well as between ECNs and dealer/specialist markets.

VIII. Conclusion

This study investigates competition of various market centers for trading of NASDAQ-listed securities. We find that the market for NASDAQ-listed securities is notably fragmented, with only slightly more than half of trades being executed through NASDAQ, and a substantial share of order flow being garnered by the three major ECNs: Island, Instinet, and Archipelago.

We show that all six participating markets differ from one another, and separation of the venues into specialist/dealer and electronic limit order book categories fails to fully capture the differences among the venues. We find that while ECNs as a group generally have lower trading costs than the dealer/specialist exchanges, trading through Island is notably cheaper than trading through Archipelago.

We surmise that, in case of the ECNs, the depth of the limit order book determines the type of trading clienteles that the networks service and show that a comparatively low depth on Island and Instinet, at times, diverts informed traders from these two market centers, partially re-routing informed order flow to Archipelago and NASDAQ.

Quote competition for NASDAQ stocks is significantly more rigorous than that for the NYSE stocks. ECNs, especially Archipelago, are highly competitive on quotes: the networks participate in the NBBO formation to almost the same degree as NASDAQ dealers. ECNs however also receive a notable share of order flow during periods when they do not post the best quotes. We attribute this phenomenon to informed traders' sacrificing the best price for the anonymous transacting that ECNs are able to provide, and to the fact that larger market orders routed to the ECNs are split up during execution due to low inside depth.

We find that approximately 14% of the NBBO spreads are either locked or crossed during our three-month sample period, demonstrating the extent of quote competition and the cost of fragmentation. We suggest that a significant number of the non-positive spreads is caused by traders' seeking to receive rebates used by the ECNs as a reward for limit order submissions. The only venue that is able to attract additional order flow during the non-positive spread periods is Island.

We use a multiple logistic regression to analyze trade executions. As opposed to simple models of discrete choice, this unordered regression provides valuable insight into the execution process by evaluating all trading venues at once. The results show that the ECNs are capable of competing with NASDAQ on quotes, while AMEX and Chicago use non-price methods to attract trades. The model also reveals that the venues are able to attract more orders while participating in both sides of the NBBO. On dealer/specialist exchanges, this phenomenon may be caused by the fact that investors are unwilling to trade with a dealer who might have information that causes him to only quote one side. On the ECNs, however, higher trading volume often causes the quotes to converge, creating an illusion of low spread – high volume causality, while the relationship is, in fact, reversed.

Overall, this study suggests that although competition among trading venues is able to reduce trading costs; it may also appear harmful for market participants, as certain venues become unable to provide quality executions in a timely manner due to decreases in the limit order book depth. Recently, NASDAQ officials have been undertaking steps to make the market more ECN-like and thus attract more trading activity by raising the level of trading anonymity. We show that market forces have already partially redirected informed order flow to NASDAQ and propose that introducing more anonymity may exacerbate this process, leading the national market back to the cream-skimming era.

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Table I
Trade Market Shares

Reported are percentage shares of trades and trade volume executed on each of the six sample trading venues. We consider trades that were completed in the 100 largest NASDAQ-listed common stocks, between 9:30 a.m. and 4 p.m. EST, during the period of April-June 2003. Panel A presents market share as a percentage of trades while panel B presents market share as a percentage of trade volume by trade size. Panel C presents market share as a percentage of trading volume for stocks separated by trading activity quintiles (with quintile 1 being the most active and quintile 5 being the least active). *p*-Values are for hypotheses that market shares across trading venues and trade sizes/quintiles are identical.

	NASDAQ	AMEX	Chicago	Island	Instinet	Archipelago	*p*-value
Panel A: Market share, % of sample trades							
All trades	51.59	0.02	0.66	17.12	11.30	19.31	0.000
100 to 499	50.14	0.01	0.54	17.69	12.09	19.54	0.000
500 to 4,999	55.78	0.04	1.09	15.42	8.76	18.91	0.000
5,000 to 9,999	73.56	0.06	1.21	10.55	3.83	10.79	0.000
10,000 or more	87.43	0.25	1.10	4.33	1.73	5.17	0.000
p-value	0.000	0.351	0.011	0.000	0.000	0.000	
Panel B: Market share, % of sample trade volume by trade size							
All trades	62.30	0.08	1.05	13.23	7.72	15.62	0.000
100 to 499	48.34	0.01	0.67	18.62	12.25	20.11	0.000
500 to 4,999	58.79	0.05	1.20	14.15	7.82	17.99	0.000
5,000 to 9,999	73.81	0.06	1.22	10.39	3.74	10.77	0.000
10,000 or more	91.47	0.29	1.23	2.67	1.12	3.22	0.000
p-value	0.000	0.000	0.004	0.000	0.001	0.000	
Panel C: Market share, % of sample trade volume by trading activity quintile							
Quintile 1	62.30	0.07	1.08	13.75	7.45	15.34	0.000
Quintile 2	61.28	0.09	1.13	12.65	8.53	16.32	0.000
Quintile 3	63.89	0.13	0.99	11.70	7.66	15.63	0.000
Quintile 4	63.02	0.07	0.79	12.25	7.79	16.08	0.000
Quintile 5	62.57	0.08	0.23	12.51	8.15	16.46	0.000
p-value	0.000	0.060	0.002	0.000	0.000	0.000	

Table II
Order Execution on ECNs

Reported are the percentage shares of orders that are executed by the electronic communications networks during the sample period. The aggregate data for stock symbols, execution venues, and order characteristics are obtained from the Dash-5 database compiled in accordance with SEC Rule 11Ac1-5. Orders larger that 9,999 are not reported by the database and therefore are not reported. The results are reported as shares of non-cancelled orders executed on the venue they had been submitted to in the total number of orders of the same type reported as covered by this venue. *p*-Values are for hypotheses that shares of executed orders across trading venues and trade sizes are identical.

	Island	Instinet	Archipelago	*p*-value
Panel A: Executed market orders, % of submitted orders				
Overall	-	17.27	49.58	0.000
100-499	-	20.95	52.81	0.000
500-4,999	-	17.56	49.98	0.000
5,999-9,999	-	16.81	43.91	0.000
p-value	-	0.000	0.000	
Panel B: Executed marketable limit orders, % of submitted orders				
Overall	42.59	50.47	52.65	0.000
100-499	45.75	57.51	56.26	0.000
500-4,999	42.83	49.92	51.61	0.000
5,999-9,999	40.25	47.92	54.71	0.000
p-value	0.000	0.000	0.000	

Table III
Execution Costs and Information Shares

Reported are averages of trade execution cost statistics (in cents) computed across sample quotes and trades. The *effective half-spread* is the amount by which the trade price exceeds (for customer buys) or is below (for customer sells) the midpoint of the contemporaneous NBBO quote. Information shares are calculated using the vector error correction model (VECM) that delivers the lower and upper bounds of the estimated information shares (with the sample separated into quintiles, with quintile 1 being the most active stocks and quintile 5 being the least active). A trade is recorded as *price improved* when a customer buy (sell) is executed at a price below (above) the best contemporaneous ask (bid) quote. A trade is executed *outside NBBO* when the price is above (below) the NBBO ask (bid) quotes for customer buys (sells). Trades are designated as customer buys and sells according to the algorithm described by Ellis, Michaely, and O'Hara (2000). *p*-Values are for a hypothesis that the results across trading venues and trade sizes/quintiles are identical.

	NASDAQ	AMEX	Chicago	Island	Instinet	Archipelago	*p*-value
Panel A: Effective half-spread by trade size, cents							
Overall	1.10	1.90	1.04	0.71	0.84	0.93	0.000
100 to 499 shares	1.00	2.37	0.95	0.64	0.84	0.92	0.000
500 to 4,999 shares	1.44	1.36	1.21	1.01	0.82	0.97	0.000
5,000 to 9,999 shares	0.74	1.84	0.67	0.51	0.60	0.56	0.042
10,000 or more	0.68	2.02	1.01	0.52	0.45	0.58	0.000
p-value	0.000	0.000	0.000	0.000	0.000	0.000	
Panel B: Effective half-spread by volume quintile, cents							
Quintile 1	0.61	1.87	0.76	0.51	0.54	0.58	0.000
Quintile 2	0.81	2.62	1.08	0.73	0.73	0.76	0.000
Quintile 3	1.00	2.30	1.32	0.93	0.91	0.95	0.000
Quintile 4	1.19	3.11	1.69	1.10	1.06	1.11	0.000
Quintile 5	1.53	3.01	1.91	1.41	1.34	1.34	0.000
p-value	0.000	0.000	0.124	0.000	0.000	0.000	
Panel C: Information shares' upper-lower bounds, %							
Overall	0.54-0.16	0.62-0.02	0.56-0.17	0.26-0.11	0.31-0.15	0.38-0.13	
Quintile 1	0.32-0.16	0.45-0.18	0.54-0.33	0.26-0.15	0.31-0.23	0.41-0.25	
Quintile 2	0.41-0.18	0.62-0.31	0.56-0.31	0.21-0.13	0.31-0.18	0.38-0.20	
Quintile 3	0.50-0.29	0.47-0.02	0.55-0.17	0.20-0.14	0.26-0.16	0.29-0.16	
Quintile 4	0.54-0.27	0.57-0.17	0.47-0.27	0.22-0.12	0.24-0.15	0.33-0.14	
Quintile 5	0.52-0.33	0.58-0.42	0.58-0.31	0.22-0.11	0.26-0.15	0.31-0.15	
Panel D: Executions at prices other than NBBO quotes							
Percent price improved	24.14	15.91	9.11	54.27	22.98	10.67	0.000
Percent executed outside NBBO	7.46	34.50	10.62	8.39	6.07	5.13	0.000

Table IV
Quote-based Competition Statistics

Reported is the summary of measures of quote competitiveness of the sample market centers. An exchange is *at inside bid and/or ask*, if it participates in formation of one or both sides of the NBBO. An exchange is at *both inside bid and ask*, when it participated in formation of both sides of the NBBO. An exchange is *alone at inside ask or bid*, if it single-handedly forms either side of the NBBO. An exchange is *alone at both bid and ask*, if it forms the NBBO by itself. A quotation has *time priority*, if it is alone at the inside, or has been placed earlier that all other inside quotes. A(n) bid (ask) *quote matches the NBBO* at time *t*, if the quote is posted at time *t*, appears equal to the bid (ask) inside quote, and the inside quote is equal to the inside quote at time *t-1*. A(n) bid (ask) *quote improves NBBO* at time *t*, if the quote is posted at time *t*, appears equal to the bid (ask) inside quote, and the bid (ask) inside quote is higher (lower) that the bid (ask) inside quote at time *t-1*. A(n) bid (ask) *quote is left alone at NBBO* at time *t*, if the quote is posted at time *t-n*, where $n > 0$, the quote appears equal to the bid (ask) inside quote, and the bid (ask) inside quote is lower (higher) than the bid (ask) inside quote at time *t-1*; or the bid (ask) inside quote is equal to the bid (ask) inside quote at time *t-1*, but the quote appears alone at NBBO starting at time *t*. *p*-Values indicate the results of testing a hypothesis that the measures across different trading venues are identical.

	NASDAQ	AMEX	Chicago	Island	Instinet	Archipelago	*p*-value
Panel A: Time-weighted averages, % of trading time							
At inside bid and/or ask	89.92	30.90	4.21	52.51	85.25	81.86	0.000
At both inside bid and ask	50.24	22.72	0.54	13.09	34.18	33.64	0.000
Alone at inside ask	11.18	1.90	0.65	2.83	7.48	6.58	0.000
Alone at inside bid	11.91	2.00	0.63	2.80	7.01	5.57	0.000
Alone at both bid and ask	0.97	0.05	0.00	0.08	0.43	0.38	0.000
Panel B: Trade-weighted averages, % of sample trades							
At inside bid and/or ask	86.52	30.74	3.08	54.17	80.92	71.85	0.000
At both inside bid and ask	50.31	15.24	0.07	13.40	31.93	28.98	0.000
Alone at inside ask	18.20	5.21	0.35	5.50	12.70	9.99	0.000
Alone at inside bid	18.81	5.10	0.28	5.65	12.43	8.68	0.000
Alone at both bid and ask	3.57	0.34	0.00	0.23	1.16	1.02	0.000
Panel C: Time priority, % of quotes posted by a venue							
Time priority at bid	50.38	14.20	1.45	21.65	37.74	37.09	0.000
Time priority at ask	52.56	14.44	1.29	21.85	36.96	36.37	0.000
Panel D: NBBO matching and altering, % of quotes posted by a venue							
Quote matches NBBO	5.85	6.85	4.09	9.91	11.61	5.61	0.000
Quote improves NBBO	2.72	3.81	2.16	2.13	3.06	2.23	0.000
Quote is left alone at NBBO	3.41	10.49	21.88	5.10	3.73	1.99	0.000
Panel E: Quote matching and altering, % of similar cases							
Quote matches NBBO	29.97	4.85	0.04	17.35	35.24	42.53	0.000
Quote improves NBBO	42.71	8.25	0.07	11.42	28.43	51.83	0.000
Quote is left alone at NBBO	40.70	17.28	0.51	20.79	26.38	35.03	0.000

Table V
Percentage of Volume Conditional on Quotes

Reported are the shares of trading volume executed by each exchange during four different states of quote competitiveness. As previously, we consider only the quotes and trades that were posted and completed in the 100 largest NASDAQ-listed common stocks, between 9:30 a.m. and 4 p.m. EST, during the period of April-June 2003. We differentiate among four stages of quote competitiveness: *at both inside bid and ask* includes trades completed while an exchange was quoting at the both sides of NBBO; *at best ask (bid) only* includes trades completed when an exchange was quoting just the inside ask (bid); *at neither best bid, nor ask* includes the trades completed while an exchange is not quote-competitive. The results are divided into panels according to the trade size. *p*-Values are for hypothesis that results across trading venues are identical.

	NASDAQ	AMEX	Chicago	Island	Instinet	ArcaEx	*p*-value
Panel A: All trades							
At both inside bid and ask	75.59	27.28	1.06	52.27	72.55	65.12	0.000
At best ask only	10.42	2.16	0.34	4.26	8.02	8.52	0.000
At best bid only	9.94	2.06	0.27	4.24	6.91	8.03	0.000
At neither best bid, nor ask	4.05	68.49	98.33	39.23	12.51	18.32	0.000
Panel B: 100 to 499 shares							
At both inside bid and ask	65.42	52.69	0.69	46.39	63.18	62.14	0.000
At best ask only	14.34	6.47	0.60	5.58	10.10	10.95	0.000
At best bid only	13.97	6.50	0.49	5.63	9.11	10.46	0.000
At neither best bid, nor ask	6.27	34.34	98.22	42.40	17.61	16.45	0.000
Panel C: 500 to 4,999 shares							
At both inside bid and ask	76.99	40.12	1.32	37.08	80.21	56.26	0.000
At best ask only	10.06	4.28	0.36	3.48	6.23	7.03	0.000
At best bid only	9.41	3.99	0.32	3.44	5.20	6.57	0.000
At neither best bid, nor ask	3.54	51.60	97.99	56.00	8.36	30.14	0.000
Panel D: 5,000 to 9,999 shares							
At both inside bid and ask	79.61	45.44	1.45	81.17	83.57	78.15	0.000
At best ask only	9.11	4.05	0.21	2.23	6.40	7.60	0.000
At best bid only	8.27	2.04	0.11	2.03	4.00	6.85	0.000
At neither best bid, nor ask	3.02	48.47	98.23	14.57	6.03	7.41	0.000
Panel E: 10,000 or more shares							
At both inside bid and ask	81.54	17.51	0.63	85.59	82.38	84.33	0.000
At best ask only	7.76	0.61	0.11	1.66	6.63	5.45	0.000
At best bid only	7.55	0.71	0.02	1.46	3.38	4.84	0.000
At neither best bid, nor ask	3.14	81.17	99.23	11.29	7.61	5.38	0.000

Table VI
Locked and Crossed Markets

The table examines the shares of zero and negative NBBO spreads in quotations placed between 9:30 a.m. and 4:00 p.m., for the 100 largest NASDAQ-listed stocks, in June 2003. A zero NBBO spread occurs when an inside ask quote equals to the inside bid quote. When a zero NBBO spread is in effect, the market is considered to be locked. A negative NBBO spread occurs when an inside ask quote is lower that a contemporaneous inside bid quote. When a negative NBBO spread is in effect, the market is considered to be crossed. The results are tested for consistency, and *p*-values indicate the results of testing a hypothesis that the shares of negative, zero, and non-positive spreads are identical.

Month/Date	Negative spreads, %	Zero spreads, %	Total non-positive spreads, %
Panel A: All Months			
April	2.13	11.47	13.60
May	2.28	12.36	14.64
June	2.24	12.43	14.67
Panel B: June			
2-Jun	2.60	13.74	16.34
3-Jun	1.40	13.07	14.47
4-Jun	1.27	13.56	14.83
5-Jun	2.16	12.49	14.65
6-Jun	6.75	12.99	19.75
9-Jun	1.67	13.72	15.39
10-Jun	1.64	13.63	15.27
11-Jun	1.80	13.48	15.28
12-Jun	1.74	12.13	13.88
13-Jun	3.21	12.33	15.54
16-Jun	1.20	12.10	13.31
17-Jun	2.00	13.09	15.09
18-Jun	3.75	13.14	16.88
19-Jun	3.72	12.57	16.29
20-Jun	2.03	10.87	12.90
23-Jun	2.25	11.33	13.59
24-Jun	1.63	11.09	12.72
25-Jun	2.02	10.58	12.59
26-Jun	1.33	11.51	12.84
27-Jun	1.59	11.87	13.46
30-Jun	1.29	11.81	13.10
Mean	2.24	12.43	14.67
p-value	*0.40*	*0.67*	*0.54*

Table VII
Posting of Quotes During Locked and Crossed Markets

Reported is the summary of measures of quote competitiveness during the periods of non-positive NBBO spreads. Quotations being investigated were placed in the 100 largest NASDAQ-listed common stocks, between 9:30 a.m. and 4 p.m. EST, in June 2003. An exchange is *at inside bid and/or ask*, if it participates in formation of one or both sides of the NBBO. An exchange is at *both inside bid and ask*, when it participated in formation of both sides of the NBBO. An exchange is *alone at inside ask or bid*, if it single-handedly forms either side of the NBBO. An exchange is *alone at both bid and ask*, if it forms the NBBO by itself. Panel A, presents the results for the locked market instances (zero NBBO spreads); while Panel B presents the results for the crossed market instances (negative NBBO spreads). Results are weighted by the amount of time between two consecutive quotations. *p*-Values are for the hypothesis that results across trading venues are identical.

	NASDAQ	AMEX	Chicago	Island	Instinet	Archipelago	*p*-value
Panel A: Time-weighted averages for zero spread instances, % of trading time							
At inside bid and/or ask	7.53	3.45	0.11	4.41	7.42	5.74	0.000
At both inside bid and ask	0.00	0.00	0.00	0.00	0.28	0.01	0.058
Alone at inside ask	1.80	0.49	0.02	0.92	1.99	1.66	0.000
Alone at inside bid	2.05	0.52	0.03	0.96	2.15	0.88	0.000
Alone at both bid and ask	0.00	0.00	0.00	0.00	0.02	0.00	0.189
Panel B: Time-weighted averages for negative spread instances, % of trading time							
At inside bid and/or ask	0.98	1.01	2.57	0.49	1.02	0.87	0.000
At both inside bid and ask	0.00	0.00	0.00	0.00	0.06	0.00	0.281
Alone at inside ask	0.17	0.40	0.12	0.10	0.29	0.17	0.000
Alone at inside bid	0.23	0.39	0.59	0.10	0.23	0.15	0.000
Alone at both bid and ask	0.00	0.00	0.00	0.00	0.03	0.00	0.414

Table VIII
Determinants of Trade Executions

Reported are the results of a multinomial logistic regression for an unordered response, with the dependent variable equal to 0, if an exchange of execution is NASDAQ, and is equal to 1, 2, 3, 4, and 5 for, respectively AMEX, Chicago, Island, Instinet, and Archipelago. Analysis considers customer buy trades that occurred from 9:30 a.m. to 4 p.m., EST, on five consecutive dates (June 2nd through June 6th, 2003). The regressors are: dummy variables for each exchange indicating that the venue is at the NBBO (6 dummies for best ask and 6 dummies for best bid), market order imbalance, number of trades in the preceding 10 minutes, volume (in hundreds of shares), and a dummy variable indicating that the market is crossed or locked. The probabilities are modeled according to the Newton-Raphson maximum likelihood algorithm. The model is adjusted for fixed effects and non-spherical errors by allowing the procedure to assume clustering across stocks and to use the Huber-White estimator. Regression coefficients are presented only for the intercept. Results for the regressor are represented by the marginal effects, where the superscripts indicate the outcome of significance testing.

	AMEX	Chicago	Island	Instinet	Archipelago
Intercept	-9.4003	-5.3641	-1.4179	-1.6507	-1.2198
At best ask:					
NASDAQ	0.0000	-0.0001*	-0.018***	-0.0090***	-0.0302***
AMEX	0.0000*	0.0003	0.0060	-0.0052	0.0013
Chicago	0.0000	0.0099***	-0.0013	-0.0054	-0.0030
Island	0.0000	0.0005***	0.0838***	-0.0077	0.0040**
Instinet	0.0000***	0.0004***	-0.0007*	0.0276***	0.0268***
Archipelago	0.0000***	0.0003***	0.0033***	-0.0073	0.1017***
At best bid:					
NASDAQ	0.0000**	0.0002	-0.0111***	-0.0058***	0.0008
AMEX	0.0000***	0.0009**	-0.0078	0.0078	-0.0077
Chicago	0.0000	0.0025***	-0.0047	0.0008	0.0169
Island	0.0000	0.0002*	0.0348***	-0.0010	0.0158
Instinet	0.0000	0.0001	-0.0113***	0.0033	0.0101
Archipelago	0.0000	-0.0002	-0.0121***	0.002**	0.0323***
Order imbalance	0.0000***	0.0004***	0.0108***	0.0073***	0.0099***
# of trades in preceding 10 minutes	0.0000	0.0001***	0.0029***	0.0023***	0.0111***
Trade size, 100 shares	0.0000	0.0001**	-0.0181***	-0.0173***	-0.0070***
Non-positive spread	0.0000	-0.0002	0.0607***	0.0008	-0.0194

*** Significant at 0.01 level
** Significant at 0.05 level
* Significant at 0.10 level

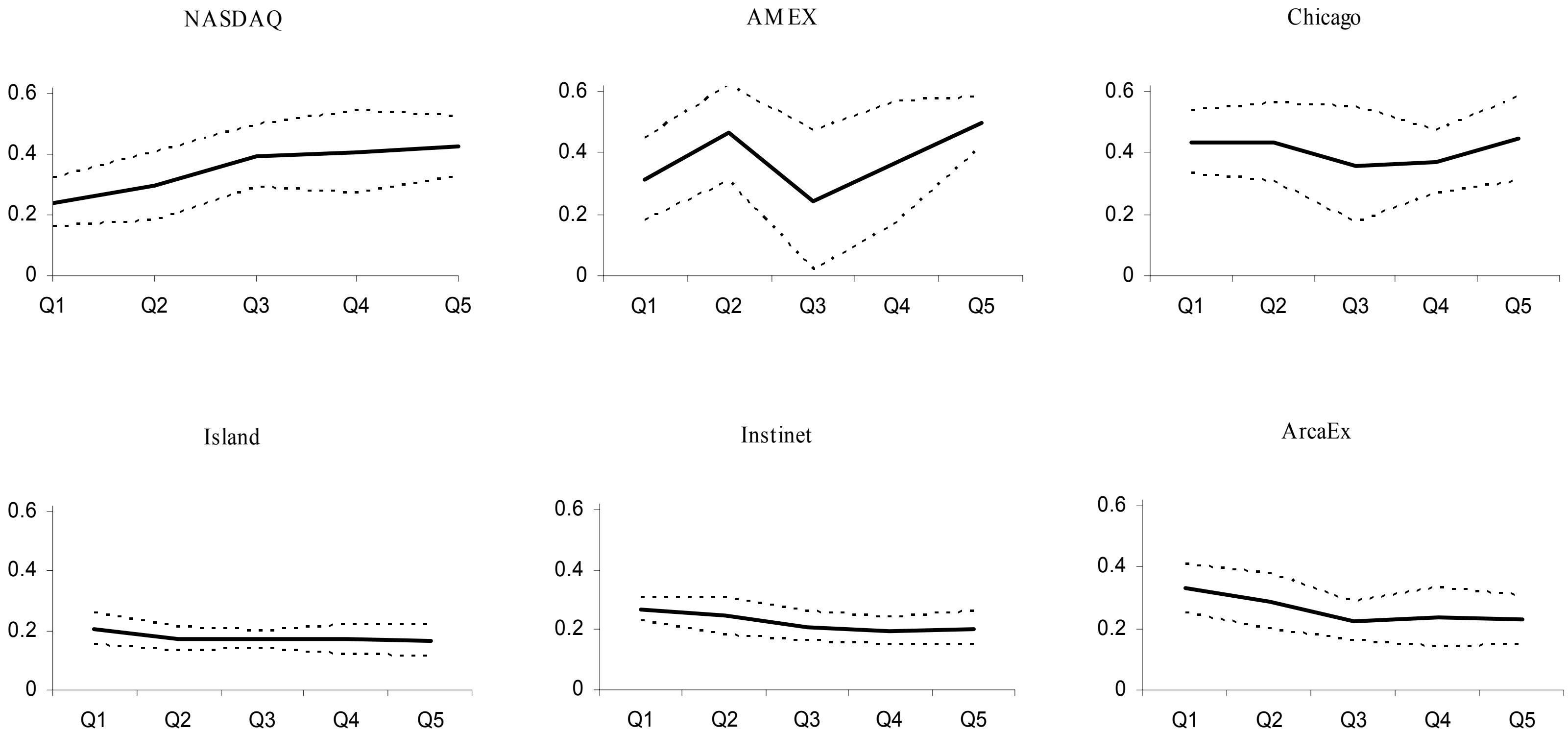

Figure 1: Information shares by quintile.
Displayed are the information share graphs. The dotted lines represent the upper and lower bounds of VECM information share estimation. The bold lines represent the hypothetical mean information share.

Appendix

Reported are the summary statistics for the sample stocks when grouped into quintiles based upon trading activity. Quintile 1 contains the most active stocks, while quintile 5 consists of the least active stocks. Number of trades, volume, dollar volume, price, trade size statistics are derived from the TAQ database, whereas market capitalization and return data comes from CRSP.

Quintile		Number of trades	Volume	Dollar volume	Price	Trade size	Market Capitalization	Return
1	Mean	32,081	24,800,483	397,243,117	16.26	747.86	40,097	13.31
	Std. dev.	18,970	18,321,371	390,825,594	10.89	314.60	66,467	72.06
2	Mean	17,526	7,769,197	227,018,686	29.45	446.34	15,734	5.02
	Std. dev.	4,177	1,505,026	156,575,643	21.02	100.56	22,950	36.22
3	Mean	10,063	3,887,378	119,390,151	31.20	392.84	8,379	17.92
	Std. dev.	1,775	366,881	52,421,766	14.68	115.29	4,265	37.90
4	Mean	6,081	1,918,356	61,642,797	33.48	308.36	5,135	9.81
	Std. dev.	1,448	596,147	31,241,910	17.51	60.52	3,436	28.42
5	Mean	3,062	885,273	29,455,782	36.07	267.99	3,298	1.74
	Std. dev.	1,094	556,853	12,028,280	11.17	58.49	1,191	17.16